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ORIGINAL PAPER

Shifting cultivation effects on creek water quality around Barkal Upazila in Chittagong Hill Tracts, Bangladesh

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Abstract: We report the effects of shifting cultivation on water quality in 16 creeks investigated once in 2007 and twice in 2008 in 16 apparently similar small neighboring watersheds, each of 3 to 5 ha, at four locations around Barkal sub-district under Rangamati District of Chittagong Hill Tracts in Bangladesh. Concentrations of SO_4^{2-} and K^+, and pH in creek water were lower, and NO_3-N and Na^+ concentrations were higher in shifting-cultivation land compared to land with either plantation or natural forest or a combination of these cover types. Shifting cultivation effects on some water quality parameters were not significant due to change in land cover of the watershed between two sampling periods either through introduction of planted tree species or naturally regenerated vegetation. Conductivity and concentrations of HCO_3^-, PO_4^{3-}, Ca^{2+} and Mg^{2+} in creek water showed no definite trend between shifting cultivation and the other land cover types. At one area near the Forest Range Office of Barkal, creek water pH was 5.8 under land cover with a combination of shifting cultivation and plantation. At this area Na^+ concentration in shifting-cultivation land ranged from 32.33 to 33.00 $mg \cdot L^{-1}$ and in vegetated area from 25.00 to 30.50 $mg \cdot L^{-1}$ in 2007. At another area, Chaliatali Chara, SO_4^{2-} concentration in a shifting-cultivation watershed ranged from 4.46 to 10.51 $mg \cdot L^{-1}$, lower than in a vegetated watershed that ranged from 11.69 to 19.98 $mg \cdot L^{-1}$ in 2007. SO_4^{2-} concentration in this shifting-cultivation area ranged from 1.28 to 1.37 $mg \cdot L^{-1}$ and in the vegetated area from 1.37 to 3.50 $mg \cdot L^{-1}$ in 2008.

Keywords: Shifting cultivation; Creek water quality; Chittagong Hill Tracts; Riparian vegetation; Land cover; Bangladesh

Introduction

Chittagong Hill Tracts (CHTs) is the only mountainous region in Bangladesh and is comprised of 74% hilly. The hillocks of CHTs are the continuation of the Himalayan range possessing most hills <1,000 m elevation and few above this. Bangladesh is located in south-east Asia and has a sub-tropical monsoon climate. CHTs before 1960 were endowed with luxuriant growth of natural forests when only 11 tribal communities lived in small populations in this hilly region and practiced shifting cultivation. Then this agricultural land use was environmentally sustainable with rotation periods of more than 20 years. This cultivation system developed rapidly during 1960–1970 due to massive loss of arable land for construction of a hydroelectric project at Kaptai. In the 1980s, forced migration of large numbers of people from the lowland plains to the CHTs not only degraded the hilly landscape, but also resulted in massive deforestation and ecological problems. Many tracts leased to non-local people for rubber plantations, did not yield the expected output (ADB 2001). Widespread political and social unrest and over exploitation of resources, including illicit tree felling, were increasing due to the shortage of suitable land, commercial plantation (mainly of teak) and unsustainable strategies for forest management. Shifting cultivation in CHTs increased many fold over the years and natural forests were converted to shrub-forest with few scattered trees interspersed with barren land and shifting-cultivation crops such as paddy, banana, and sesame. During reconnaissance surveys prior to water sampling, vegetation types were increasingly subject to fragmentation by rotational shifting cultivation and re-growth of natural vegetation due to high rainfall in this tropical region. Natural re-growth of herbs, shrubs and trees recolonized lands previously cultivated. The hill tracts are thus a mosaic of vegetation cover interspersed with deforested areas. Previous studies in upland watersheds reported that shifting cultivation caused losses of fertile topsoil (Gafur et al. 2003), reduced abundance of microorganisms (Miah et al. 2010), changed water quality (Haque et al. 2010), and sedimentation occurred in stream channels and in the man-made Kaptai Lake (Karmakar et al. 2009). Our study was conducted to describe water quality of creeks and seepages passing through shifting-cultivated lands and compare this with water quality in other watersheds supporting varied vegetation cover around Barkal Upazila in Rangamati hill district. Our objective was to determine whether ex-

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panding shifting cultivation on shortened cultivation cycles of 2−3 years has negative effects on water quality. This is a land management issue because runoff from shifting-cultivated land and other land-use types is discharged to Kaptai Lake, the largest reservoir in South-east Asia (Fernando 1980). The lake has been used by the Fisheries Department of Bangladesh Government for commercial fish culture and by large numbers of people living in this mountainous region for domestic uses.

Materials and methods

Study area

Our study area encompassed small watersheds of 2−5 ha at Barkal Upazila (Fig. 1), under Rangamati hill district in Bangladesh. Barkal Upazila covers 760.88 km^2 at 92°11' N to 92°28' N and 23°07' E to 22°39' E adjacent to Mizoram state of India. Barkal Upazila is comprised of 87% hills and hillocks of the Himalayan formation and the remainder is the drainage basin of Karnaphuli River. Upazila is part of the northern and eastern hill physiographic unit with sedimentary rock formations, mainly of shale and Haplic alfisols. Topsoils are sandy loams with mixed minerals having low moisture-holding capacity, moderately permeable with excessive drain. Mineral surface soils are slightly sticky with no saline phase, alkali petrocalcic and acid sulphate phase. In 1991, Barkal was a sparsely populated area with 40 persons per square kilometer, 70% indigenous peoples, and 30% migrants from the lowland plains (Rahman 2007).

Study watersheds

In shifting-cultivated areas, creek water was sampled once on 16 August 2007 and re-sampled at the same site on 19 July 2008 in 16 different watersheds of 2−5 ha in area. We selected creeks for water sampling based on vegetation structure and composition, and to avoid sewage outfalls from human habitation. We sampled surface water in 16 flowing creeks around Barkal Upazila (Fig. 1) of 9 different land cover combinations. Between the two sampling periods, land cover changed due to establishment of plantations and natural regrowth of vegetation. We used the same site identification numbers in this section (Tables 1 and 2) as in the results section to indicate the same site to enable description of changes in vegetation between the two sampling seasons. To make comparisons between land-cover types, parallel creeks were grouped. Thus, 16 creeks were assigned to 4 groups. Each of the sites with changed vegetation was described

Group 1:
This group includes six creeks under five land-cover combinations located about 1 km east of the Barkal Upazila headquarters and beside Barkal Forest Range Office (Sl. No. 1-6). During the first sampling period in August 2007, shifting-cultivated land included one creek, one creek had shifting-cultivated land on one side and bushy forest on the other, one creed had bamboo forest on both sides, two creeks had natural forest on both sides, and one creek had plantation on one side and natural forest on the other. Creeks in this group are described below to explain variation in land use and vegetation:

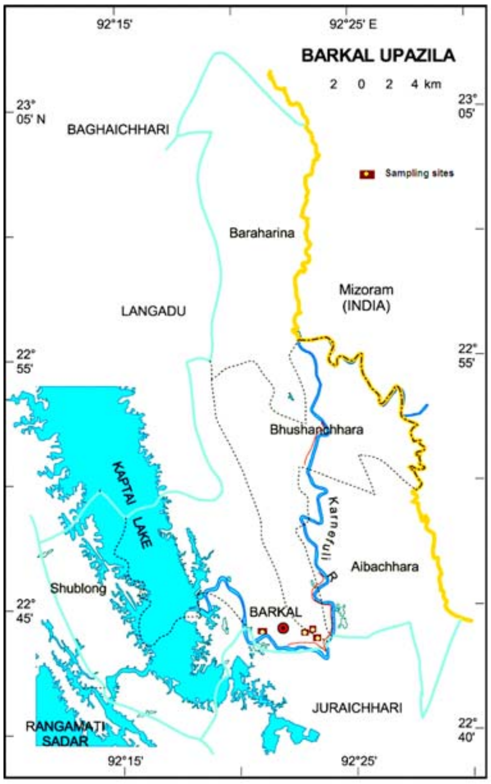

Fig. 1 Creek water sampling sites around BarkalUpazila in Chittagong Hill Tracts

1. Shifting-cultivation land: Current year shifting-cultivated areas were present on both sides of this creek in 2007. Major crops were paddy, banana, *Gmelina arborea* (gamar) and *Tectona grandis* (teak). This was the only creek with this land cover flowing at the base of a 25% hill slope. Part of this shifting-cultivation area was under mixed *G. arborea* and *T. grandis* plantation during re-sampling in 2008.
2. Shifting-cultivated and natural forest: Current year shifting-cultivation was on one side of the creek and the other side was covered with natural shrub-forest in 2007. Major crops were paddy and banana. This was the only creek with this land cover flowing at the base of a 25% hill slope. Here, the shifting-cultivated area was a *G. arborea* plantation in 2008.
3. Bamboo and natural forest: The upper ridge of the hill was inaccessible due to dense bamboo stands on both sides of the creek in 2007. This was the only creek with this land cover at the base of a 30% hill slope. Bamboo forest was changed to mixed *T. grandis* and *G. arborea* plantation in 2008.
4. Natural forest 1: This hill was fully covered with natural forest with dense undergrowth in 2007. This was one of two creeks having this land cover combination flowing at the base of a 35% hill slope. One side of this natural forest was replaced by *T. grandis* plantation in 2008.
5. Natural forest 2: The land-cover of this creek was similar to

the above creek with the exception that the upper part of the hill was disturbed due to livestock grazing and fuel wood collection. This was the second creek with this land cover combination, and flowed at the base of a 30% hill slope. The land-cover of 2007 was changed to mixed plantation of *T. grandis* and *G. arborea* during re-sampling in 2008.

Table 1 Creek and seepage water quality in shifting-cultivation and other land-use combinations around Barkal Upazila, Rangamati on August 2007

Sl. No.	Land cover combinations	Group	Conductivity ($\mu S \cdot cm^{-1}$)	HCO_3 ($mg \cdot L^{-1}$)	P ($mg \cdot L^{-1}$)	Na ($mg \cdot L^{-1}$)	K ($mg \cdot L^{-1}$)	Ca ($mg \cdot L^{-1}$)	Mg ($mg \cdot L^{-1}$)	TDS ($mg \cdot L^{-1}$)	Fe ($mg \cdot L^{-1}$)
1	Shifting cultivation	1	202.00	140	0.44	32.33	1.65	12.46	1.33	105.20	0.02
2	Shifting cultivation + Natural forest		285.33	200	0.53	33.00	2.67	16.74	1.39	130.33	0.01
3	Bamboo + Natural forest		260.33	180	0.24	25.00	1.77	16.48	1.35	108.00	0.01
4	Natural forest 1		209.50	150	0.48	30.50	2.08	10.28	1.34	79.00	0.02
5	Natural forest 2		246.67	220	0.55	30.00	3.35	12.19	1.36	83.33	0.02
6	Plantation + Natural forest		170.67	90	0.29	28.33	2.27	8.28	1.30	95.0	0.01
7	Shifting cultivation 1	2	322.67	200	0.49	30.00	2.30	20.76	1.39	140.3	0.02
8	Shifting cultivation 2		206.67	160	0.35	28.00	1.95	12.32	1.32	108.5	0.02
9	Shifting cultivation 3		148.00	120	0.32	29.00	2.33	5.66	1.24	65.50	0.01
10	Shifting cultivation 4		182.00	140	0.40	27.00	1.88	7.68	1.31	45.23	0.02
11	Shifting cultivation + Natural forest		298.33	180	0.66	26.67	3.02	12. 63	1.35	42.22	0.01
12	Natural forest 1		146.00	180	0.52	25.00	2.93	6.51	1.27	55.24	0.03
13	Natural forest 2		137.33	140	0.57	25.67	3.48	6.88	1.30	60.12	0.01
14	Shifting cultivation + Plantation	3	120.67	100	0.42	26.67	2.63	5.15	1.23	100.52	0.02
15	Shifting cult. + Plantation+ Natural forest		244.67	150	0.42	26.00	2.60	10.28	1.33	85.25	0.01
16	Shifting cult. + Plantation+ Natural forest	4	155.67	160	0.49	27.00	3.17	16.61	1.28	43.40	0.02

Table 2. Creek water quality in shifting-cultivation and other land-use combinations around Barkal Upazilla, Rangamati, in July 2008

Sl. No.	Land cover combinations	Group	Conductivity ($\mu S \cdot cm^{-1}$)	HCO_3 ($mg \cdot L^{-1}$)	P ($mg \cdot L^{-1}$)	Na ($mg \cdot L^{-1}$)	K ($mg \cdot L^{-1}$)	Ca ($mg \cdot L^{-1}$)	Mg ($mg \cdot L^{-1}$)	TDS ($mg \cdot L^{-1}$)	Fe ($mg \cdot L^{-1}$)
1	Shifting cultivation	1	201.67	294.83	0.21	25.43	1.13	5.93	1.09	73.33	0.03
2	Shifting cultivation + Natural forest		252.33	386.33	0.16	23.50	1.22	11.08	1.20	123.33	0.03
3	Bamboo + Natural forest		252.85	183.00	0.34	27.31	1.88	17.76	2.30	110.00	0.04
4	Natural forest 1		229.67	244.00	0.53	34.26	3.38	15.75	2.30	90.00	0.02
5	Natural forest 2		244.67	355.83	0.63	38.00	3.72	14.42	2.81	90.00	0.02
6	Plantation + Natural forest		228.67	284.67	0.31	36.33	2.82	10.56	2.60	80.00	0.01
7	Shifting cultivation 1	2	319.33	183.00	0.18	31.09	2.37	19.06	1.54	143.33	0.02
8	Shifting cultivation 2		202.67	264.33	1.03	18.40	1.80	8.19	2.76	93.33	0.05
9	Shifting cultivation 3		131.33	305.00	0.12	24.00	1.13	4.02	2.75	50.00	0.01
10	Shifting cultivation 4		120.33	244.00	0.24	17.00	1.57	7.30	2.23	40.00	0.02
11	Shifting cultivation + Natural forest		148.00	244.00	0.13	25.56	1.50	6.14	2.04	30.00	0.01
12	Natural forest 1		144.62	366.00	0.21	23.82	2.87	6.22	2.43	56.67	0.03
13	Natural forest 2		145.67	193.17	0.23	23.57	3.48	6.25	1.60	63.33	0.03
14	Shifting cultivation + Plantation	3	243.00	183.00	0.23	21.62	2.60	5.56	1.66	95.00	0.03
15	Shifting cult. + Plantation+ Natural forest		246.00	325.33	0.42	24.20	2.67	11.19	2.37	86.67	0.01
16	Shifting cult. + Plantation+ Natural forest	4	61.67	122.00	0.13	25.00	1.18	2.61	0.63	20.00	0.02

6. Plantation and natural forest: Five year-old shifting-cultivation of banana was on one side of the creek with *G. arborea* with scattered undergrowth and the other side was covered with dense forest including bamboo in 2007. This was the only creek having this land cover combination, and flowed at the base of a 35 % hill slope. The natural forest cover of 2007 was converted to *G. arborea* plantation in 2008.

Group 2:

This group contained seven creeks under three different land cover combinations in 2007, and was located about 800 m east of Upazila headquarters and beside Barkal hospital complex (Sl. No. 7-13). In this group, shifting-cultivation occurred along four

creeks, one creek had shifting-cultivation on one side and shrub-forest on the other, two creeks had natural forest cover. Creeks in this group are described below to explain variation in land use and vegetation:

7. Shifting-cultivation 1: Shifting-cultivation of the current year was on both sides of the creek and the bank was covered with natural bamboo. Major crops were paddy, banana, *G. arborea* and *Vitex glabrata* (goda). This was one of the 4 creeks with this land cover flowing at the base of a 43% hill slope. Land cover was unchanged in 2008. The other three creeks in this group also had current year shifting-cultivation in 2007, with the exceptions mentioned below for each.

8. Shifting-cultivation 2: Both sides of this creek were sometimes used for cattle grazing. Major crops were paddy and sesame. This creek was at the base of a 30% hill slope. Part of this shifting-cultivation area was under young *G. arborea* plantation in 2008.

9. Shifting-cultivation 3: Major crops on both sides of this creek were paddy, *G. arborea* and *V. glabrata*. This creek was at the base of a 48% hill slope. Part of this area was under *G. arborea* plantation in 2008.

10. Shifting-cultivation 4: Major crops on both sides of this creek were paddy, *G. arborea* and *V. glabrata* in 2007. This creek was at the base of a 40% hill slope. Both sides of this creek were changed to *G. arborea* plantation in 2008.

11. Shifting-cultivation and natural forest: Current year shifting-cultivation was on one side of the creek and the other side was covered with natural forest. Major crops were paddy and banana. Natural forest mainly of *V. glabrata* and *Albizia procera* (shirish) trees had dense undergrowth. This was the only creek with this land cover flowing at the base of a 55% hill slope. The shifting-cultivation was changed to *G. arborea* and *T. grandis* plantation during re-sampling in 2008.

12. Natural forest 1: This hill was fully covered with natural forest along with bamboo with dense undergrowth. This was one of the two creeks having this land cover combination, and flowing at the base of a 50% hill slope. Vegetation was unchanged at the time of re-sampling.

13. Natural forest 2: This creek was similar to the above creek in land cover. This was the other creek in this group flowing by the side of 55% hill slope. The land cover above this creek was similar in 2007 and 2008.

Group 3

This group was located about 775 m east of Upazila headquarters and contained two creeks under three land-cover combinations in 2007 (Sl. No. 14-15). Each of the creeks is described below:

14. Shifting-cultivation and plantation: The first creek of this group had shifting-cultivation on one side and 25-year *T. grandis* and and 6-year *G. arborea* plantation with dense undergrowth on the other side. Major crops were paddy and banana. This creek was flowing by the side of a 40% hill slope. The land cover above this creek remained unchanged during re-sampling in 2008.

15. One side shifting-cultivation and the other side plantation and natural forest: Second creek of this group had current year shifting-cultivation area on one side and in patches about 7-year-old *G. arborea* plantation along with undergrowth, naturally growing bamboo and other vegetation present on the other side of the creek. Major crops were paddy, banana, and sesame. This creek was flowing by the side of a 45% hill slope. Here, part of the shifting-cultivation area in 2007 was changed to *G. arborea* plantation in 2008.

Group 4

16. Shifting-cultivation, plantation and natural forest: This group contained only one creek 250 m west of Upazila headquarters (Sl No. 16). On one side of the creek 6-year old *T. grandis* plantation with scattered undergrowth grew on abandoned shifting-cultivation and on the other side was dense natural shrub-foresta. This creek was flowing by the side of a 60% hill slope. Vegetation was similar above the creek in 2007 and 2008.

Collection and analyses of water samples

Water samples were collected from creeks in triplicate in 200 mL polyethylene bottles and cooled at 4°C in an icebox. Samples were carried immediately to the laboratory and filtered using Whatman paper No. 42. Water pH was determined from filtrate using a TOA pH meter, conductivity by conductivity meter and TDS by TDScan. Water samples were then stored in the refrigerator at 4°C for subsequent analyses. Base cations such as Ca^{2+} and Mg^{2+} were determined using Perkin-Elmer, Shelton, CT Atomic Absorption Spectrophotometer in the regional laboratory of the Soil Resource Development Institute (Petersen 2002). Dissolved phosphate was analyzed using the stannous chloride and ammonium molybdate method (APHA 1998), SO_4^{2-} by the $BaCl_2$ method, NO_3-N by the salicylation-sodium hydroxide method, Fe by the hydroxyl ammonium chloride-orthophenanthroline method in a Jenway Spectrophotometer, and K and Na by flame photometer (Huq and Alam 2005).

Results and Discussion

Water pH

Water pH near Barkal Forest Range Office (Sl. No. 1-6) in 2007 and 2008 showed a lower pH value in shifting-cultivation watersheds than that in either natural forest or combinations of natural forest and plantation (Fig. 2a). In 2008, water pH was distinctly lower in creeks flowing through shifting-cultivation than either in plantation or combination of plantation and natural forest. In all land cover-types either alone or in combination, pH value increased after change of vegetation in 2008. Water pH in land cover combinations of shifting-cultivation and plantation was 5.8 and in all other combinations ranged from 6.07 to 6.77. Water pH in Chaliatali Chara (Sl. No. 7-13) was distinctly lower in all four shifting-cultivation watersheds than in either natural forest or a combination of shifting-cultivation and natural forest in 2007 and 2008. The few exceptions in 2008 re-sampling might have been due to changes in vegetation. Water pH in shift-

ing-cultivation ranged from 5.17 to 5.33 and in natural forest from 5.67 to 5.77 in 2008 (Table 2). In re-sampling, water pH in shifting-cultivation was 5.07, in combinations of shifting cultivation with plantation, pH ranged from 5.87 to 6.37 and in combinations of either plantation or natural forest, pH ranged from 5.73 to 6.20. Water pH levels at Barkal Hospital Complex (Sl. No. 14-15) and at Parihat Chara (Sl No. 16) were similar due to the absence of any distinct shifting-cultivation. However, pH was higher in 2008 than in 2007. Creek water pH of Barkal Upazila showed lower pH influenced by soil properties inherited from parent material rather than vegetation cover. The creek draining shifting-cultivation showed lower pH, which might be due to increased leaching of cations from the soil. This result confirmed the findings of Haque et al (2011). They also observed similar changes in shifting-cultivation watersheds in this region. Change in land cover from shifting-cultivation in 2007 to plantation in 2008 might increase pH, indicating an improvement of the site.

Water conductivity

Water conductivity near Barkal Forest Range Office (Sl. No. 1-6) in shifting-cultivation was lower than in all other land cover types in combination or alone both in 2007 and in 2008. In 2007, water conductivity in shifting-cultivation was 202.00 $\mu S \cdot cm^{-1}$ and in all other vegetation ranged from 205.80 to 285.83 $\mu S \cdot cm^{-1}$. In 2008, creek water in shifting-cultivation watersheds had conductivity of 201.67 $\mu S \cdot cm^{-1}$ and in all other vegetation singly and in combination ranged from 228.67 to 252.85 $\mu S \cdot cm^{-1}$. This relationship at Chaliatali Chara showed the reverse trend from that near Barkal Forest Range Office: Almost consistently higher conductivity showed in shifting-cultivation than in natural forest both in 2007 and 2008, with one exception (Tables 1 and 2). In shifting-cultivation, conductivity ranged from 148.00 to 322.00 $\mu S \cdot cm^{-1}$ and in natural vegetation, from 140 to 366 $\mu S \cdot cm^{-1}$ in 2007 and 2008. No general trend was found for water conductivity near Barkal Hospital Complex either in 2007 or in 2008.

Hydrogen carbonate concentration

No clear effect of land cover was found on bicarbonate content in water at any location. However, at all vegetated areas bi-carbonate concentration was higher in 2008 than in 2007 (Tables 1 and 2). Near Barkal Forest Range Office (Sl. No. 1-6) HCO_3^- concentration in shifting-cultivation ranged from 140 to 200 $mg \cdot L^{-1}$ and in vegetated areas, from 90 to 220 $mg \cdot L^{-1}$ in 2007, while in shifting-cultivation it was 294.83 $mg \cdot L^{-1}$ and in vegetated areas ranged from 183 to 386 $mg \cdot L^{-1}$ in 2008. Bicarbonate concentration at Chaliatali Chara (Sl. No. 7-13) in shifting-cultivation ranged from 120 to 200 $mg \cdot L^{-1}$ and in vegetated areas, from 140 to 180 $mg \cdot L^{-1}$ in 2007, while in shifting-cultivation it ranged from 183 to 305 $mg \cdot L^{-1}$ and in vegetated areas, from 193 to 366 $mg \cdot L^{-1}$ in 2008. High alkalinity was more closely related to divalent cations (Ca^{2+} and Mg^{2+}) than to Na^+. In the streams where concentrations of SO_4^{2-} and divalent cations were low, alkalinity was closely related to Na^+ production by weathering (Nakagawa and Iwatsubo 2000).

Suphate concentration

Concentration of SO_4^{2-} near Barkal Forest Range Office (Sl. No. 1-6) showed no general trend between shifting-cultivation and vegetated areas. At Chaliatali Chara (Sl. No. 7-13) and near Barkal hospital complex, SO_4^{2-} concentration was lower in shifting-cultivation than in vegetated areas in 2007 and 2008 (Fig. 2c). At Chaliatali Chara, SO_4^{2-} concentration in shifting-cultivation ranged from 4.46 to 10.51 $mg \cdot L^{-1}$ in 2007 and 4.13 to 6.72 $mg \cdot L^{-1}$ in 2008. In vegetated areas it ranged from 11.69 to 19.98 $mg \cdot L^{-1}$ in 2007 and 11.51 to 19.13 $mg \cdot L^{-1}$ in 2008. Sulphate concentration in waters near shifting-cultivation was lower indicating reduction of this compound due to burning of vegetation, which enhanced removal of SO_4^{2-} through runoff water during heavy rains. Through this process, SO_4^{2-} content became unavailable from deep percolation or from draining through the soil column to the creek.

Nitrate concentration

Concentration of NO_3^- in jhum-cultivation areas was higher than in vegetated area in 2007 and 2008 with few exceptions (Fig. 2b). Near Barkal Forest Range Office (Sl. No. 1-6), NO_3^- concentration in shifting-cultivation ranged from 3.67 to 4.65 $mg \cdot L^{-1}$ and in vegetated areas from 1.46 to 4.16 $mg \cdot L^{-1}$ in 2007. In shifting-cultivation it was 3.35 $mg \cdot L^{-1}$ and in vegetated areas it ranged from 2.63 to 4.30 $mg \cdot L^{-1}$ in 2008. Concentrations of this compound at Chaliatali Chara (Sl. No. 7-13) in shifting-cultivation ranged from 2.08 to 3.09 $mg \cdot L^{-1}$ and in vegetated areas from 2.04 to 2.48 $mg \cdot L^{-1}$ in 2007, while in shifting-cultivation it was 3.28 $mg \cdot L^{-1}$ and in vegetated areas it was 1.37 to 2.50 $mg \cdot L^{-1}$ in 2008. Nitrate concentrations differed significantly by land-cover type in paired watersheds. This compound leached more from shifting-cultivation than from vegetated areas in both years. With the change in land cover in 2008, the Barkal Forest Range Office watershed showed lower NO_3^- content. Many studies confirmed the link between the upland agriculture and nitrogen export to streams (Salvia-Castellvi et al. 2005; Wayland et al, 2003; Donner et al. 2004; Woli et al. 2004; Buck et al. 2004). The primary cause of the change in stream chemistry was disruption of the forest nitrogen (N) cycle (Likens et al. 1970; Bormann and Likens 1979). After afforestation, nitrate concentrations declined due to increased nitrogen uptake by the growing forest leading up to canopy closure (Nisbet et al. 1995; Miller 1981). Higher nitrate concentration was also observed in stream water that drained through deforested catchments (Liu et al. 2000; Haque et al. 2010). Haque et al. (2010) reported that nitrate concentration increased in streams with increases in shifting-cultivation and decreased with the presence of natural forest. Removing the forest canopy decreases plant N uptake, accelerates N mineralization from organic matter, and increases the rates of nitrification (Bormann and Likens 1979). Hence, stream water NO_3^- concentration is mainly regulated by stand age, i.e., by vegetation regrowth (Tokuchi and Fukushima 2009).

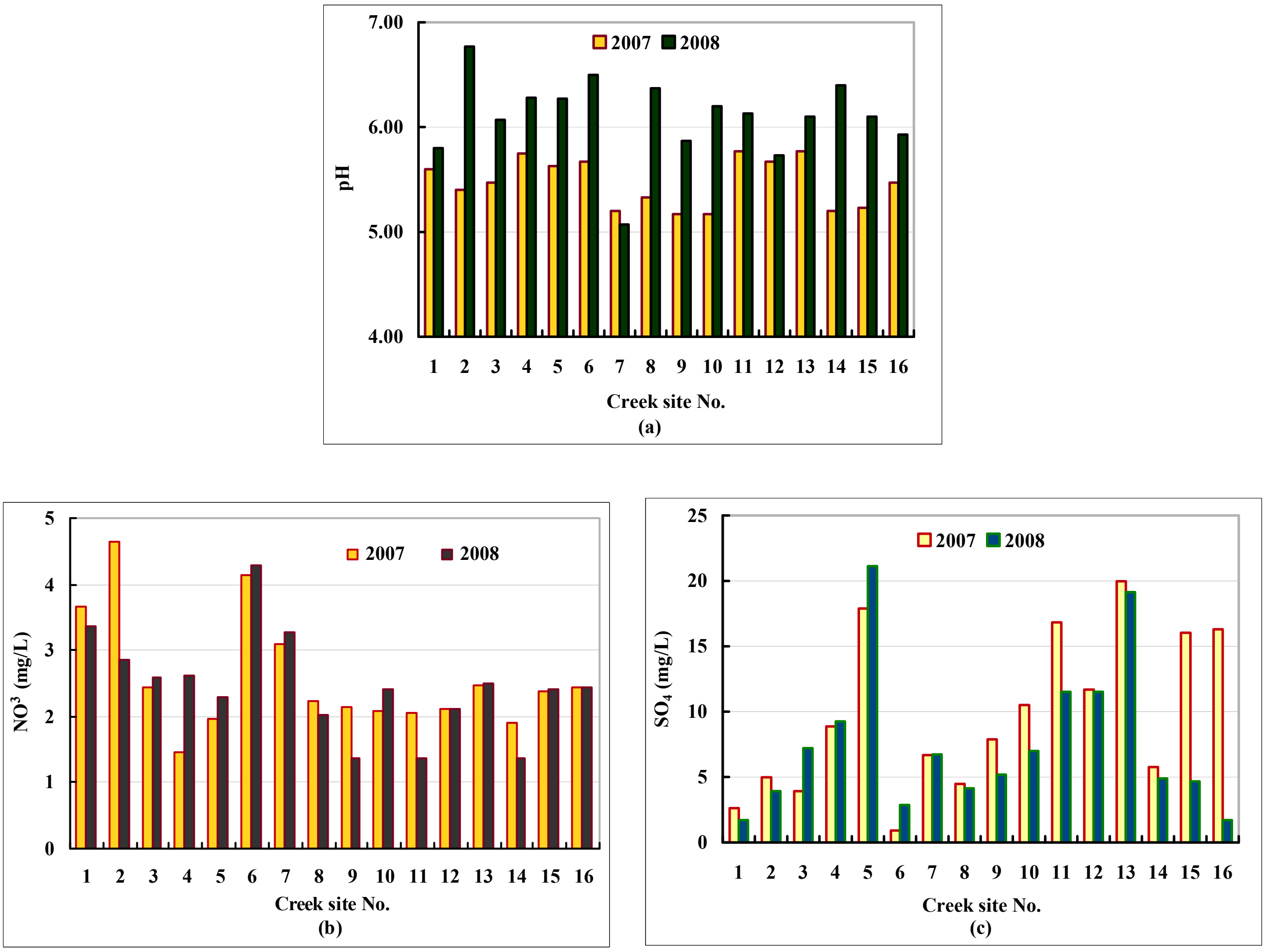

Fig. 2 Stream water (a) pH, (b) NO3 and (c) SO4concentration in 2007 and 2008 around BarkalUpazila, Rangamati. Legend: 1 Shifting cultivation; 2 Shifting cultivation + Natural forest; 3 Bamboo + Natural forest; 4 Natural forest 1; 5 Natural forest 2; 6 Plantation + Natural forest; 7 Shifting cultivation 1; 8 Shifting cultivation 2; 9 Shifting cultivation 3; 10 Shifting cultivation 4; 11 Shifting cultivation+ Natural forest; 12 Natural forest 1; 13 Natural forest 2; 14 Shifting cultivation + Plantation; 15 Shifting cultivation + Plantation+ Natural forest; 16 Shifting cultivation + Plantation+ Natural forest.

Dissolved phosphorus concentration

No trend in PO_4^{3-} content was found for different land cover types at all sites in 2007 or 2008. Near Barkal Forest Range Office (Sl. No. 1-6) PO_4^{3-} concentration in shifting-cultivation varied from 0.44 to 0.53 mg·L^{-1} and in vegetated areas from 0.29 to 0.55 mg·L^{-1} in 2007. In 2008, in shifting-cultivation it was 0.21 mg·L^{-1} and in vegetated areas ranged from 0.16 to 0.63 mg·L^{-1}. Phosphorus content at Chaliatali Chara (Sl. No. 7-13) in shifting-cultivation ranged from 0.32 to 0.49 mg·L^{-1} and in vegetated areas from 0.52 to 0.57 mg·L^{-1}. In 2008, in shifting-cultivation it ranged from 0.12 to 1.03 mg·L^{-1} and in vegetated areas from 0.13 to 0.24 mg·L^{-1}. Phosphorus concentration in creek water in the same watershed did not vary significantly due to land cover changes between years. Upland agriculture practices in watersheds of Barkal were mainly non-intensive, hence showed very low and uneven P content in creek water. This result reveals that P concentration is mainly dependent on the geology of the area rather than catchment land use. A similar conclusion was discussed regarding geological attributes of P concentrations by Tokuchi and Fukushima (2009) in Japan.

Sodium and potassium concentration

Sodium concentration in waters near shifting-cultivation was higher than in vegetated areas near Barkal Forest Range Office (Sl. No. 1-6) and Chaliatali Chara (Sl. No. 7-13). Concentration of this element in a shifting-cultivation watershed near Barkal Forest Range Office was distinctly higher, ranging from 32.33 to 33.00 mg·L^{-1}, than in vegetated watershed where it varied from 25.00 to 30.50 mg·L^{-1} in 2007. At Chaliatali Chara, Na^+ concentration in a shifting-cultivation watershed was higher, varying from 27.00 to 30.00 mg·L^{-1}, than in vegetated areas where it ranged from 25.00 to 26.67 mg·L^{-1} in 2007. In 2008 in shifting-cultivation, it ranged from 18.00 to 31.09 mg·L^{-1} and in veg-

etated areas 17.00 to 23.82 mg·L^{-1}. Sodium content near Barkal Hospital complex in 2007 was nearly similar, and in 2008 varied from 21.62 to 24.60 mg·L^{-1} in re-sampling.

Concentration of K^+ in shifting-cultivation was lower than in vegetated areas at two locations, Barkal Forest Range Office (Sl. No. 1-6) and Chaliatali Chara (Sl. No. 7-13), and similar at one location in 2007 and 2008. Concentration of K^+ at the first location with shifting-cultivation ranged from 1.65 to 2.67 mg·L^{-1} and in the vegetated area ranged from 1.77 to 3.35 mg·L^{-1} in 2007. In 2008 in shifting-cultivation it was 1.13 mg·L^{-1} and in vegetated areas ranged from 1.22 to 3.72 mg·L^{-1}. In Chaliatali Chara, K^+ concentration in shifting-cultivation varied from 1.88 to 2.33 mg·L^{-1} and in vegetated areas from 2.93 to 3.48 mg·L^{-1} in 2007. In 2008 in shifting-cultivation it ranged from 1.13 to 2.37 mg·L^{-1} and in vegetated areas from 1.50 to 3.48 mg·L^{-1}. Potassium concentration did not vary in Barkal Hospital Complex area (Sl. No. 14-15) in 2007 or 2008.

Ca^{2+} and Mg^{2+} concentrations

Both Ca^{2+} and Mg^{2+} contents showed no definite trend in 2007 or 2008 between shifting-cultivation and vegetated areas. In 2007, Ca^{2+} contents in shifting-cultivation ranged from 12.46 to 16.74 mg·L^{-1} and in vegetated areas from 8.28 to 16.48 mg·L^{-1}, while in 2008 in shifting-cultivation it was 5.93 mg·L^{-1} and in vegetated areas varied from 10.56 to 17.76 mg·L^{-1}. At Chaliatali Chara (Sl. No. 7-13), Ca^{2+} concentration in shifting-cultivation varied from 5.66 to 20.76 mg·L^{-1} and in vegetated areas from 6.51 to 6.88 mg·L^{-1} in 2007, while in 2008 in shifting-cultivation it was 19.06 mg·L^{-1} and in vegetated area ranged from 4.02 to 8.19 mg·L^{-1}.

Concentration of Mg^+ in shifting-cultivation near Barkal Forest Range Office (Sl. No. 1-6) ranged from 1.33 to 1.39 mg·L^{-1} and in vegetated area 1.30 to 1.36 mg·L^{-1} in 2007, while in shifting-cultivation it was 1.09 mg·L^{-1} and in vegetated areas ranged from 1.20 to 2.81 mg·L^{-1} in 2008. Concentration of Mg^+ at Chilatali Chara (Sl. No. 7-13) in shifting-cultivation ranged from 1.24 to 1.39 mg·L^{-1} and in vegetated areas from 1.27 to 1.35 mg·L^{-1} in 2007, while in shifting-cultivation it was 1.54 mg·L^{-1} and in vegetated areas varied from 1.60 to 2.43 mg·L^{-1} in 2008.

Concentration of K^+ in shifting-cultivation was lower and Na concentration higher than vegetated areas in two locations, near Barkal Forest Range Office and Chaliatali Chara, both in 2007 and 2008. However, K^+ concentration at other sites such as near Barkal Hospital Complex and Parihat Chara (Tables 1 and 2), where vegetation was unchanged between 2007 and 2008, did not vary, indicating the influence of vegetation on mobility of this element in the soil horizon.

TDS and total Fe

Total dissolved solids in stream water were more concentrated in shifting-cultivation catchments than in adjacent natural forest or plantation catchments. And iron in creek water showed no definite trend between shifting-cultivation and other land-cover types singly or in combination (Tables 1 and 2).

Conclusion

In shifting-cultivation catchments, NO_3-N, HCO_3^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, conductivity and total dissolved solids were higher than in catchments draining through natural forest. In this hilly region bamboo frequently occurs near streams and on hills. The NO_3-N and P concentrations in bamboo-dominated catchments were significantly lower than in adjacent shifting-cultivation areas. Significant increase in pH and decrease in NO_3-N and sodium concentrations in stream water occurred one year after shifting cultivation was replaced by a combination of artificial plantation and naturally regenerating vegetation. Shifting-cultivation employs slash-and-burn methods, which destroy vegetation completely. Within one year after abandonment of cultivation, natural revegetation was observed in this study. These results suggest that large-scale planting of hilly watersheds to mixed plantations in combination with natural revegetation and encouragement of bamboo stands that grow naturally might be an option for improvement of water quality in this degraded watershed.

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